

RECENT RESULTS FROM PHENIX

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I report on results from the PHENIX collaboration for the first RHIC run, where gold ions were collided at $\sqrt{s_{NN}} = 130 \text{ GeV}$. In order to study initial conditions, PHENIX has measured the ratio between anti-protons and protons, the transverse energy, and charged multiplicity as a function of collision centrality. These measurements allow us to extract some information on the initial density of created partons, the baryon density, the energy density, and particle production. In order to probe the formation of a possible new state of matter, PHENIX has measured the neutral pion and unidentified hadron transverse momentum spectra. We find a deficit compared to the expectations from simple nucleon-nucleon scaling. These novel results are consistent with expectations that high p_T leading particles will be suppressed in the presence of the formation of a plasma.

1 Introduction

Can we create matter in which quarks are free? What makes up the majority of the mass around us? What makes up the spin of the proton? These are some of the questions that the PHENIX collaboration, which utilizes the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, will address. RHIC is a versatile collider which can produce Au+Au collisions up to 200 GeV/u, polarized p+p collisions up to 500 GeV, as well as ion combinations in between. During the first RHIC run during the summer of 2000, gold ions were collided at 130 GeV/u from which the PHENIX detector recorded 5 million events.

The PHENIX detector is designed to measure a broad range of signals including rare penetrating probes, such as photons, electrons, and muons, that are sensitive to the formation of a deconfined state of matter. In order to accomplish this, PHENIX is a complex integrated detector system that has a high rate capability, high granularity, good mass resolution, and good particle ID. The central detector was approximately 50% instrumented for the summer 2000 experimental run.¹

In this paper I report on a subset of PHENIX's results from the first year of data taking. I subdivide these results into two categories: initial conditions and hard probes. The results are intriguing in their own right and show the promise of the program over the coming years.

2 Initial Conditions

Initial conditions are required to characterize the state of nuclear matter formed. To fully understand the initial conditions a comprehensive program that includes e+A, p+A, and a variety of A+A species are needed. However, even with A+A collisions at full energy we can begin to get a handle on some of the initial conditions.

From the first year of data of Au+Au collisions at full energy, PHENIX has measured the ratio between anti-protons and protons, the transverse energy, and charged multiplicity as a function of collision centrality. This allows us to extract some information on the initial density of created partons, the baryon density, the energy density, and particle production.

2.1 Gluon saturation

Gluons can begin to fuse with high enough gluon density, limiting the parton production. If the gluon density is indeed high enough to saturate, it implies that the system would thermalize quickly. This would be important as it has implications on the initial energy density achieved.

If the parton production is limited, we expect that the final state charged particle yields to also be limited. Therefore, PHENIX's measurement² of the charged particle multiplicity as a function of number of participants constrains models. (See Fig. 1). In particular, the results disfavor models that have a fixed saturation scale,³ while models in which the saturation scale changes with centrality can describe the data.⁴ While the latter class of models can describe the data, it is not a unique description. Further measurements with different species and energies, and perhaps ultimately e+A collisions, are needed to explore whether the initial gluon density saturates.

2.2 Baryon density

The measure of the baryon and energy density is required to map out the phase diagram of nuclear matter. Lattice calculations, which predict that nuclear matter undergoes a phase transition, are calculated at zero baryon density.

In a preliminary analysis, PHENIX has measured $\bar{p}/p = 0.64 \pm 0.01 \pm 0.08$. This represents a net baryon density significantly lower than at the SPS, and is approaching the low baryon density limit where lattice calculations are preformed. The ratio of \bar{p}/p shows only a weak centrality dependence and little or no p_T .

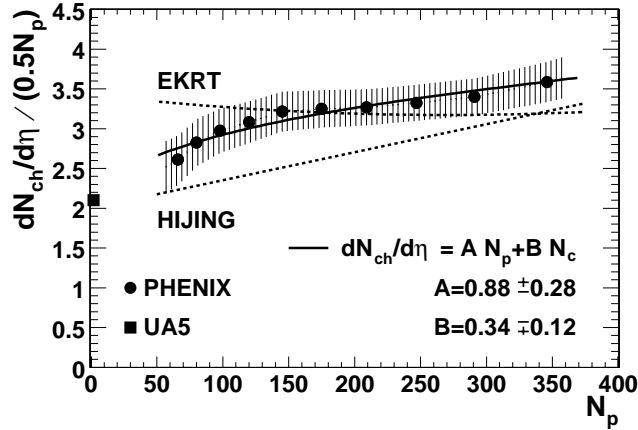


Figure 1. Charged-particle pseudorapidity density per participant pair vs. the number of participants.²

2.3 Energy density

Lattice calculations indicate the phase transition to occur at zero baryon density and an energy density $\epsilon_{crit} \approx 0.6 - 1.8 \text{ GeV}/fm^3$. Assuming a boost invariant expanding cylinder of dense nuclear matter in which a thermalized system is reached after a formation time, τ_0 , Bjorken derived a formula from which the measured transverse energy, E_t can be related to the energy density, ϵ_{Bj} . For the most central events, we measure⁵ $\epsilon_{Bj} = 4.6 \text{ GeV}/fm^3$ for a formation time of 1 fm/c. This is roughly 1.5 to 2 times higher than previous experiments. However, we expect the formation time to be smaller at RHIC than at the SPS, perhaps indicating a much higher energy density at RHIC. For example, if the formation time is 0.2 fm we arrive at an energy density of $23 \text{ GeV}/fm^3$. Therefore, it appears that the energy deposition is certainly adequate, so the question becomes whether a thermalized system is created fast enough before ϵ falls below ϵ_{crit} . The PHENIX program includes the measurement of direct γ 's, which should help conclude whether we are indeed producing a thermalized system.

2.4 Particle production

Many models of particle production identify two components: (A) soft interactions where production scales with the number of participating nucleons;

and (B) hard interactions where production scales with the number of binary collisions. Therefore, we write $dN_{ch}/d\eta = A \times N_{part} + B \times N_{bin}$. PHENIX has measured² $B/A = 0.38 \pm 0.19$ from our charged particle multiplicity measurement. (See Fig. 1). We also find that the transverse energy density per participant scales in a consistent manner with the charged particle density per participant.⁵ These results provide evidence for a term in the growth which scales like the number of collisions.

3 Hard Probes

It has been predicted⁶ that partons respond differently to a deconfined plasma phase compared to ordinary nuclear matter, therefore providing a probe of the formation of a plasma. Parton-parton interactions at high Q^2 occur during the very early pre-equilibrium phase of nucleon-nucleon collisions. At a high enough Q^2 , pQCD can be used to reliably calculate hard scattering rates. Using these rates and measured parton distribution and fragmentation functions, the rates of high p_T leading hadrons can be predicted.

Partons are expected to lose energy via gluon radiation in traversing a quark-gluon plasma. The partons then fragment into the hadrons which we measure. Above 2 GeV we expect the hadrons to be largely a result of jet fragmentation. Therefore, we look for a suppression of high p_T leading particles, which carry information about whether the momentum of the parton is lowered while traversing the formed matter.

3.1 PHENIX's π^0 and unidentified leading hadron measurements

PHENIX has measured⁷ the transverse momentum spectra of π^0 and unidentified charged hadrons out to ≈ 4 GeV from Year-1 of RHIC. Currently, there is no N+N data at 130 GeV to serve as a baseline, and therefore we parameterize the p+p and p+ \bar{p} charged hadron spectra and interpolate to 130 GeV. We then scale by the number of binary collisions in two different centrality classes: “peripheral” representing 60-80% and “central” representing 0-10%. For the π^0 baseline we make the additional correction due to the h/π ratio measured at the ISR. When we compare our measured leading particle spectra with the p+p baseline we find that for the peripheral centrality class it is consistent with N+N scaled by the number of collisions, while for the central centrality class it is significantly below the scaled N+N spectra. We also observe that the π^0 deficit is larger than that from the unidentified hadrons. (See Fig. 2.) This is consistent with our identified spectra measurements which show that the particle composition is a strong function of p_T .

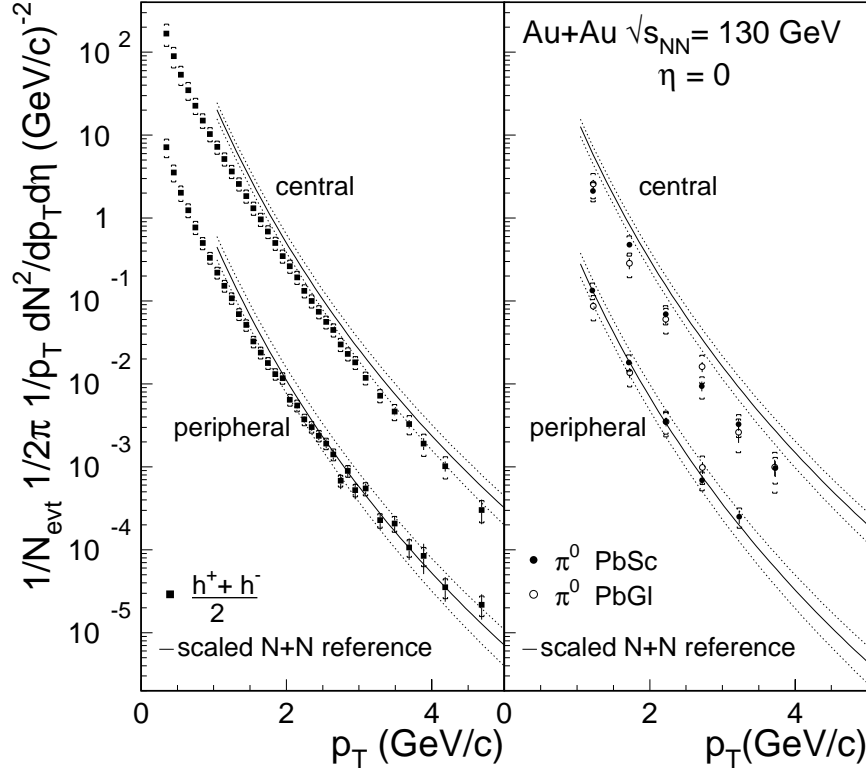


Figure 2. The yields per event at mid-rapidity for (left) charged hadrons and (right) neutral pions, with the π^0 results from the PbSc and PbGl analyses plotted separately.⁷

3.2 Complications

So far I have ignored possible complications due to nuclear effects. However, the transverse momentum spectra is known to be modified due the “Cronin effect” and quark and gluon “shadowing”.

The Cronin effect can be modeled as prior parton scattering. This has the effect of broadening the transverse momentum spectrum, which **enhances** high p_t particles. Calculations show that the largest enhancement is expected around $p_T = 4$ GeV/c, and to become small above 6 GeV/c.⁸

Nucleon structure functions are known to be modified in nuclei, translating into a **deficit** of high p_T particles. In the frame where the nucleon is

moving fast, this can be modeled as a recombination effect due to the high gluon number density at low x . The nuclear shadowing due to quarks has been measured. For the x range relevant to RHIC, $x > 10^{-2}$, it is around 10% effect. Unlike quark shadowing, gluon shadowing has not been measured. Furthermore, gluon scatter will be important at RHIC. However, in the x range relevant for RHIC is expected to be smaller than a 10% effect.⁹

Therefore, the current understanding of the known nuclear effects cannot account for our experimental observation. Our central collisions data shows significant suppression relative to the prediction without energy loss. This indicates a novel effect: the deviation from point like scaling. It is consistent with parton energy loss, but without p+p data at the appropriate energy, p+A data to verify the expectations for quark and gluon shadowing, and a larger p_T reach to eliminate the possibility contributions from collective soft effects, it is too early to make definitive conclusions.

4 Outlook

The first PHENIX run was a huge success. In addition to commissioning a complex detector, our charged particle multiplicity measurements constrain models, the energy density appears to be well above the phase transition level, and we have suggestive high transverse momentum measurements.

The second PHENIX run is ongoing. During this run we expect RHIC to achieve design luminosity. Assuming RHIC delivers the promised integrated luminosity, PHENIX will be able to measure high- p_t leading particles out beyond 10 GeV, and make measurements of the J/Ψ , ω , ϕ , and direct- γ 's. Equally as exciting, the Year-2 will include the first polarized proton collisions.

References

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